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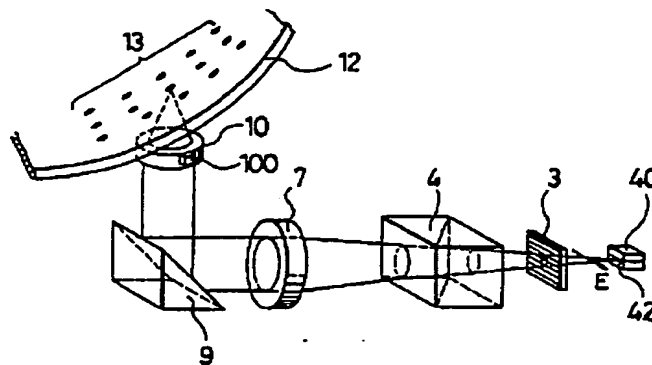
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⑩ Improvements in optical head apparatus.

⑪ An optical head apparatus comprises a laser light source (4) emitting linearly polarized light and an optical system including a diffraction grating (3) and a beam splitter (4) for transferring light from the source to a recording medium (12) and for transferring light from the recording medium (12) to a detector (19). A converging lens (10) serves to converge a collimated light onto the tracks (13) on the recording medium (12). The converging lens (10) is formed by moulding and techniques are adopted to minimize astigmatism.

FIG. 1



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## IMPROVEMENTS IN OPTICAL HEAD APPARATUS

### FIELD OF THE INVENTION

The present invention relates to optical head apparatus for writing data onto and reading data from a recording medium.

### BACKGROUND OF THE INVENTION

Apparatus and components of the type with which the invention is concerned are described, for example, in the following publications:

- (a) Japanese Patent Publication No 102342/1983
- (b) "Modern Optical Engineering", McGraw-Hill, N.Y. 1986
- (c) "Technique for Designing a Lens", pp. 35-36 Kogaku Kogyo Gijutsu Kyokai, Japan
- (d) "Optics", p. 158, Wiley, New York
- (e) "The Present Status of Plastics Lens", Harada, Journal of the Institute of Television Engineers of Japan, Vol. 38, No. 9 (1984), pp. 810-814
- (f) Japanese Patent Publication No 50335/1982.

In addition apparatus depicted in Fig. 3, and described hereinafter, is known.

In recent years, injection moulded plastics lenses have been used as a converging lens in optical head apparatus as the precision in moulding techniques advances. Such lenses can be formed to have aspheric surfaces, if the moulding die is machined by precision NC (numerical controlled) machines. This is in contrast to conventional glass lenses which usually have to be polished individually and which therefore are generally restricted to spherical surfaces. It has therefore been possible to replace a conventional combination of three to five spherical glass lenses by a single aspherical moulded lens.

Because the converging lens of optical head apparatus can be fabricated as a single lens by moulding in mass production, the cost of the optical head apparatus is reduced and its assembly is simplified so that the moulded plastics lenses will be increasingly used in the future.

A serious disadvantage associated with a moulded lens is the lack of uniformity in the aberration characteristics. Other problems are also encountered in the known optical head apparatus as discussed hereinafter.

### SUMMARY OF THE INVENTION

An object of the invention is to provide an improved optical head apparatus having a converging lens formed by moulding.

In its broadest aspect, the invention provides improvements in an optical head apparatus utilizing a converging lens formed by moulding which involves adjustment, setting or controlling the position of the injection gate of the lens or its position in situ with respect to the direction of linear polarization of a laser beam such that the astigmatism of the overall converging system from the associated light source to a recording medium is minimized. As a result, the writing/reproducing performance of the optical head apparatus is enhanced.

According to the invention: and as is known per se, an optical head apparatus comprises:

- a light source for emitting a laser beam with linearly polarized light,
- an optical lens or lens system for converging a light pencil derived from the laser light source onto information recording tracks on a recording medium, and
- an optical system including a beam splitter for separating light reflected from the recording medium from the light emitted by the light source. In accordance with the invention, the converging lens or lens system at least includes a lens formed by moulding, and the position of the moulded lens about the optical axis of the converging lens is adjusted to minimize astigmatism.

In some cases, the lens may be set to bring its moulding gate into a position coincident with or parallel to the direction of polarization of the light or to a position where minimal overall astigmatism occurs. In a preferred embodiment, the moulded lens is so orientated that its astigmatism tends to cancel out astigmatism due to other factors. By minimising astigmatism the invention enables the apparatus to perform at the ideal diffraction limit to optimize the reading and writing of data.

### BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood more readily, and various other features and aspects of the invention may become apparent, from consideration of the following description in conjunction with the accompanying drawings, wherein:-

Fig. 1 is a diagram showing an optical head apparatus constructed in accordance with the invention;

Fig. 2 is a diagram showing how converging lenses used in apparatuses are set up according to the invention;

Fig. 3 is a diagram showing a conventional optical head apparatus;

Fig. 4 is a graphic representation of data obtained by experiments on the variation in the astigmatism with rotation of a moulded lens;

Fig. 5 is a diagram showing how the astigmatism is produced by a parallel plane plate;

Fig. 6 is a diagram showing how the astigmatism due to image height is produced;

Fig. 7 is a diagram showing a semiconductor laser and explaining the astigmatism of such a semiconductor laser;

Fig. 8 is a diagram showing the relationship between the astigmatic difference and astigmatism;

Fig. 9 is a diagram showing the relationship between the direction of a recording track, the direction of the polarization of the light, and the direction of the gate;

Fig. 10 is a diagram showing another converging optical system in accordance with the invention.

Fig. 3 depicts a known form of optical head apparatus in which a light source such as a semiconductor laser 40 emits a light beam 2 which is linearly polarized in a direction parallel to its PN junction. A diffraction grating 3 splits the original light beam 2 into three further beams 5. A beam splitter in the form of a semitransparent mirror or half prism 4 directs the beams 5 into further components of the optical system and separates the illuminating light beams 5 from corresponding retro-reflected light beams 6. A collimator lens 7 converts the illuminating light beams 5 emerging from the beam splitter 4 into parallel light pencil beams 8 which are re-directed by a reflection prism 9 as beams 11 substantially at right angles to the beams 5. A converging lens 10 converges the parallel or pencil light beams 11 onto an information track 13 of a disk-shaped rotatably driven recording medium or carrier 12 to form corresponding light spots 14a, 14b, 14c as shown at c) in Fig. 3. For this to be achieved, the recording medium 12 is positioned at or close to the focal point of the converging lens 10. The pre-recorded information track 13 consists of pits 15 and lands 16 and the light beam 11 reflected by the recording medium 12 pass back through the converging lens 10, are re-directed by the prism 9 through the collimator lens 7 and are reflected by the half prism 4 substantially at right angles to the beams 2, 5 as reflected light beams 6. A concave lens 17 reduces the angle of convergence of the reflected light beams 6 and a cylindrical concave lens 18 causes astigmatism in the light beams 6 passed through the concave lens 17. Light detecting means 19 which comprises photo-electric detecting elements 19a to 19c receives the reflected light beams 6.

The central detector 19a receives the light beam reflected from the light spot 14a, and converts the received light into an electrical signal proportional to the intensity of the light. The intensity of the reflected light itself varies depending on whether the light spot 14a is reflected by a pit 15 or a land 16 on the recording track 13. The electrical signal is used to reproduce an audio signal, a video signal, digital data, or the like.

As the recording medium 12 rotates, the surface of the recording medium 12 may vary in position in the direction of optical axis of the object lens 10 because of unevenness, undulation, vibration and the like. Deviation in the direction of the optical axis from the focal point is detected in a known manner (literature - (a)) in accordance with the variation in the shape of the light beam received by the central photodetector element 19a, and is corrected by a servo mechanism, not shown, so that the surface of the recording medium 12 is kept at the focal point.

The rotation of the recording medium 12 also causes relative deviation in the lateral sense between the central beam creating the spot 14a and the track 13, due to meandering of track 13 and vibration. To correct the error in the lateral direction, the difference between the outputs of the photodetectors 19b and 19c corresponding to the outer beams creating the spots 14b, 14c is detected and used as a representation of the deviation between the track 13 and the spot 14a and correction is made in accordance with the detected deviation (see the literature (a) mentioned above).

To maximize the density of information stored on the recording medium in such an apparatus, the length of the pits 15 and the track pitch are made as small as possible to allow reading when the optical system from the semiconductor laser to the converging lens 10 is in the ideal state of the diffraction limit. Typically, when the laser wavelength  $\lambda = 780$  nm, and the numerical apertures (NA) of the converging lens 10 is  $NA = 0.5$ , then the spot diameter obtained by converging at the diffraction limit is about  $\lambda/NA = 1.6$  microns. The track pitch is therefore 1.6 microns, while the minimum pit length is 0.8 microns, half the minimum spot diameter.

In order for the converging system to have the characteristic of the ideal diffraction limit, it is required that

- (1) the light emitted from the semiconductor laser 40 should be conducted at or close to the state of stigmatism throughout the entire light path passing the converging lens 10 up to the spot 14, and
- (2) the semiconductor laser 40 itself does not itself have any aberration.

As discussed previously it is desirable to fabricate the converging lens 10 as a single moulded, i.e. plastics, lens and Fig. 1 depicts an optical head apparatus constructed in accordance with the invention which uses such a lens. In Fig. 1, the same components and parts have the same reference numerals as Fig. 3.

The astigmatism produced by the use of a moulded plastics converging lens 10 will now be discussed in further detail with reference to Fig. 4 which shows measurements of astigmatism in a situation where a linearly polarized parallel light beam 11 passes through the lens 10 formed by injection moulding, and is converged on a surface. The plastics material used is PMMA. The lens 10 has a gate 100 through which the plastics material was injected into the moulding die during the injection moulding process. The angle subtended between the line G connecting the gate 100 and the center of the lens 10 and the direction E of the polarization of the incident light is denoted by  $\theta$ . In Fig. 4a, the vertical axis  $W_{AS}$  represents a standard deviation value (hereinafter referred to as rms value) of the astigmatism, expressed in terms of the wavelength  $\lambda$  of the light beam and the horizontal axis represents the angle  $\theta$ . The measurement  $W_{AS}$  was made using a Fizeau's Interferometer which is common in the measurement of the astigmatism of optical components.

As will be seen from Fig. 4a,  $W_{AS}$  is smallest (about  $0.01/\lambda_{rms}$ ) when the direction of the polarization and the direction of the gate coincide with each other, i.e., when  $\theta$  is  $0^\circ$  and  $180^\circ$  while  $W_{AS}$  is largest - (about  $0.045/\lambda_{rms}$ ) when the direction of the polarization and the direction of the gate are at right angles with each other. The same measurements were conducted on 10 workpieces and the results similar to that illustrated were obtained. According to the literature (e), it is inferred that a moulded plastics lens 10 exhibits double refraction due to strain caused by internal residual stress and this is the cause of the variation in the astigmatism.

The conventional apparatus of Fig. 3 is also associated with aberration due to three factors. First, the surfaces of the parallel plane optical components such as the diffraction grating 3 and the half prism 4 through which the light beams are transmitted are inclined and not normal with respect to the optical axis of the light beams 2. Secondly, when the point of light emission of the semiconductor laser is off the optical axis of the collimator lens 40, an image height is generated so that astigmatism is generated in the collimated light beams 8. Thirdly, the light emitted from the semiconductor laser 40 itself exhibits astigmatism.

These phenomena will be described in further detail.

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- (i) Inclination of the diffraction grating 3 and/or the half prism 4.

The light beam 2 emitted from the semiconductor laser is divergent when it passes through the components 3, 4. Assume that, as shown, in Fig. 5, a parallel plane glass 30 (numerical aperture  $NA = \sin u$ ) is disposed in an optical path of a converging light beam, with the parallel plane glass 30 being inclined by  $Up'$  with respect to the optical axis 31. The astigmatic different (astigmatism) which results in such a situation is given by the following equation (1), according to the literature (b).

$$\begin{aligned}
 & A s = \ell s' - \ell t' \\
 & = \frac{t'}{\sqrt{N^2 - \sin^2 U p'}} \left[ \frac{N^2 \cos^2 U p'}{(N^2 - \sin^2 U p')} - 1 \right] \\
 & \dots (1)
 \end{aligned}$$

In the above equation,  $\ell t'$  represents the distance to the point of convergence in the surface (meridional surface) containing the normal to the parallel planes of the glass plate 30 and the optical axis, and  $\ell s'$  represents the distance to the point of convergence in the surface (sagittal surface) normal thereto.

If, in Fig. 3, showing the conventional system, the diffraction grating 3 or the half prism 4, which is a parallel plane part, is inclined, an astigmatism in accordance with the equation (1) is produced. For instance, if a diffraction grating with a refraction index  $N=1.5$  and  $t'=1.5\text{mm}$ , or a half prism with  $t'=5\text{mm}$  is inclined by  $1.0^\circ$ , the resultant astigmatic difference will be 0.17 microns or 0.17 microns or 0.56 microns, respectively.

#### (ii) Image height due to misalignment of the semiconductor laser.

Generally, when the object (which is the point of light emission of the semiconductor laser) is off the optical axis, and an image height exists, then astigmatism is produced. Fig. 8 shows results of calculation of production of an astigmatism according to literature (c). As shown in the right side of the representation, with increasing image height the point of focusing by the meridional rays and the point of focusing by the sagittal rays are separated from each other and the astigmatism is increased.

As an example, there is a collimator lens for use in an optical head apparatus, which produces an astigmatism of 10 microns for the image height corresponding to the incident angle of  $1^\circ$ , and there is an object lens for use in an optical head apparatus, which produces an astigmatism of 5 microns for the image height corresponding to the incident angle of  $1^\circ$ .

#### (ii) Astigmatism of the semiconductor laser.

The area of the point of light emission of a semiconductor laser is about 2 microns  $\times$  0.1 microns, and can be generally regarded as a point.

Fig. 7 shows an example of a double hetero-junction semiconductor laser. As shown in Fig. 7 at (a) and (b), the beam waist of the light beam or pencil emitted from the semiconductor laser chip 40 may have different dimensions: the value within the plane (x-y plane) of the junction of the semiconductor and the value within the plane (x-z plane) normal thereto may differ. Especially with gain guiding type semiconductor laser, such a difference is large. Within the normal plane (x-y plane), the point A within the mirror surface 41 forms a mode waist, whereas within the junction plane (x-z plane) the point B in the active layer 42 of the semiconductor laser chip 40, i.e., at the back of the mirror surface 41 forms a mode waist. This difference causes astigmatism. There are certain semiconductor laser chips of the gain guiding type with which the difference may be as large as about 25 microns.

As a criterion for a permissible limit for an optical system accepted as a diffraction limit optical lens, the Marechal's criterion has been used. According to this criterion, the RMS value ( $W_{rms}$ ) of the wavefront aberration must be not greater than  $0.07 \lambda$ :  $W_{rms} \leq 0.07 \lambda$  (where  $\lambda$  represents the wavelength of the light).

The relationship between the astigmatic differences discussed above in connection with three types of phenomena and the wavefront deviation will be described with reference to Fig. 8.

In Fig. 8, E represents the exit pupil of radius  $a$ . The coordinates of the pupil is expressed by (x,y). The x-direction lateral aberration  $x'$  at the sagittal image surface  $P_s$  is related to the wavefront aberration  $W$  as follows:

$$x' = \frac{R}{n'} \frac{\partial W}{\partial \bar{x}} \quad \dots (2)$$

when  $R \gg \Delta$ , i.e., when the astigmatism difference is very small, (as is assumed in fig. 7) the following equation (3) holds):

$$x' = \frac{\bar{x}}{R} \cdot \Delta \quad \dots (3)$$

Combining the equations (2) and (3),  $x'$  can be eliminated, and the wavefront aberration  $W$  can be given by the following equation (4), if  $n'$  is assumed to be 1 (unity) assuming that surrounding medium is air.

$$W = \int_0^{\bar{x}} \left( \frac{\partial W}{\partial \bar{x}} \right) d\bar{x} = \frac{1}{2} \left( \frac{\bar{x}}{R} \right)^2 \Delta \quad \dots (4)$$

The equation (4) represents the astigmatism coefficient in the Seldel's form. If the value of the equation (4) is converted into the standard deviation  $W_{rms}$  of the wavefront aberration at the least circle of confusion which is the best convergence point, the following equation (5) is obtained.

$$W_{rms} = \frac{1}{4 \sqrt{6}} N a^2 \cdot \Delta \quad \dots (5)$$

Here,  $Na = a/R$ , with  $a$  representing the radius of the exit pupil as illustrated in Fig. 8.

Thus, if the numerical aperture  $NA$  of the system is given, the astigmatic difference  $\Delta$  satisfying  $W_{rms} \leq 0.07 \lambda$  is obtained using the equation (5).

For instance, with optical head apparatus for an optical video disc, a collimating lens having  $Na$  of about 0.2 and a semiconductor laser having a wavelength of about 0.8 microns is used. In such a case, the permissible astigmatic difference for the  $W_{rms} \leq 0.07 \lambda$  is  $\lambda \leq 13.7$  microns. The permissible astigmatic difference may be exceeded by the astigmatism due to the phenomena (i), (ii) and (iii) described above, and the converging system as a whole is prevented from functioning as the diffraction limit optical system. Consequently, the optical transfer function (OTF) deteriorates as does the writing/reading performance.

As has been described, when a plastics lens is used as a converging lens of an optical head apparatus, the plastics lens itself has an astigmatism due to its moulding strain. The value may be as large as  $0.045 \lambda$ . This alone may amount to 60% or more of the permissible aberration  $0.07 \lambda$ . This has been an obstacle to securing a good writing/reading performance.

In the optical head apparatus constructed in accordance with the invention the astigmatism due to the strain of the plastic and the astigmatism due to defects in the remainder of the optical system is minimized and the converging system from the laser to the recording medium functions optimally as a diffraction limit optical system.

In the Fig. 1 system the astigmatism of the plastics moulded converging lens 10 is minimized by controlling the position of the moulding gate 100 and rotational position of the lens 10. Let it be assumed firstly that astigmatism due to the phenomena (i), (ii) and (iii) in the optical path from the semiconductor laser 40 to the point just before the converging lens 10 is relatively small, and the light beam entering the converging lens 10 is not considerably inclined with respect to the optical axis of the converging lens 10, and the light convergence is accomplished with a sufficiently small image height relative to the effective field of vision of the lens. Where the astigmatism which is produced under such conditions is about the same as or smaller than the minimum astigmatism due to the internal strain of the converging lens 10 (for example, the

astigmatism is not more than about 0.01  $\lambda$  rms in the case of the lens shown in Fig. 4), the direction of the gate and the direction of the linear polarization of the light emitted from the semiconductor laser is made to coincide with each other to produce minimal astigmatism. This is illustrated in Fig. 2a, in which the arrow E denotes the direction of the polarization and the arrow G denotes the direction of the gate 100.

In practice, the optimum angle for minimizing the astigmatism of the overall converging system is about 0° or about 180° and  $\theta$  may be adjusted (in the proximity of 0° or 180°) to the exact optimum value.

Now, let us consider a different situation in which the astigmatism due to the phenomena (i), (ii) and (iii) or the image height of the converging lens 10 is large, that is when the astigmatism is larger than the astigmatism which results when the directions E and G are in parallel with each other (i.e., the angle  $\theta$  in Fig. 4 is 0° or 180°). In this case, the angle  $\theta$  between the directions E and G is varied or adjusted to have such a value that the astigmatism which is due to the internal strain of the converging lens and which is produced at the time of entry of the linearly polarized light and the astigmatism due to the other factors cancel each other or at least minimize the astigmatism of the entire converging system.

In the discussion above, no mention has yet been made to the relationship or relative position between the direction E of the polarization and the direction of extension of the data track. However, as was disclosed in the literature (f), an optical head apparatus with better reproduction characteristics can be obtained if the direction E of the linear polarization (which direction is parallel to the junction surface 42 in the case of a semiconductor laser 40) is at right angles to the direction of the track 13. This is because the angle of the light emission is greater in the direction normal to the junction surface than in the direction parallel to the junction surface.

This is applied to the optical head apparatus constructed in accordance with the invention, as depicted in Fig. 9 which shows the relationship between the directions E and G and the direction of the track 13. Where the direction E of the polarization is set at right angles to the direction of the track 13, and where the astigmatism other than that due to the internal strain of the object (converging) lens is small (typically not more than 0.01  $\lambda$  rms as in the embodiment described), the best convergence characteristic is obtained if the direction G of the gate is set parallel with the direction E, as shown in Fig. 9(a). Where the astigmatism is larger, the best convergence characteristic is obtained if the angle  $\theta$  between the directions E and G is so adjusted that the astigmatism of the overall converging system is minimized.

In the discussion above, the converging lens 10 is assumed to be of an infinite conjugate type (parallel incidence type) but the invention is applicable where the lens 10 is a finite conjugate type is used to directly receive and converge the light emitted from the semiconductor laser 40, as illustrated in Fig. 10.

Although the invention is concerned with moulded lenses formed from plastics the invention can be realized with moulded glass lenses. Precision pressing techniques for glass have advanced in recent years, and glass converging lenses for use in optical head apparatus have been proposed. It is known that these lenses have double refraction due to internal residual stress, although perhaps to a different degree. With these press-formed glass moulded lenses, the angle of rotation about the optical axis of the lens may also be adjusted to minimize the astigmatism of the overall converging system with plastics lenses.

#### 40 Claims

##### 1. An optical head apparatus comprising:

a light source (40) for emitting a laser beam with linearly polarized light,

an optical lens or lens system (10) for converging a light beam derived from the light source onto a recording medium (12), and

an optical system including a beam splitter (4) for separating light reflected from the recording medium (14) from light emitted by the light source (40); characterized in that

the converging lens or lens system at least includes a lens (10) formed by moulding, and the position of the moulded lens (10) about the optical axis of the converging lens is adjusted to minimize astigmatism.

2. An apparatus according to claim 1; wherein the moulded lens (10) is made from an injection moulded plastics and has a gate (100) and the adjustment of the lens position caused the gate to be in a position substantially coincident with the direction of the polarization of the light source.

3. An apparatus according to claim 1, wherein the moulded lens (10) is made from an injection moulded plastics and the position of the gate (100) at the time of moulding the lens is set so that the astigmatism of the lens will tend to cancel astigmatism due to other factors.

4. An apparatus according to claim 2 or 3, wherein the moulded lens is made from PMMA.

5. An apparatus according to claim 2, 3 or 4, wherein the moulded lens is a non-spherical lens of the infinite conjugate type.

6. An apparatus according to claim 2, 3 or 4, wherein the moulded lens is a non-spherical lens of the finite conjugate type.

7. An apparatus according to any one of claims 1 to 6, wherein the light source is a semiconductor laser.

8. An apparatus according to any one of claims 1 to 7, wherein the direction of the polarization of the laser beam from the light source is substantially perpendicular to tracks (13) on the recording medium.

9. An apparatus according to claim 1, wherein the moulded lens is formed from glass.

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FIG. 1

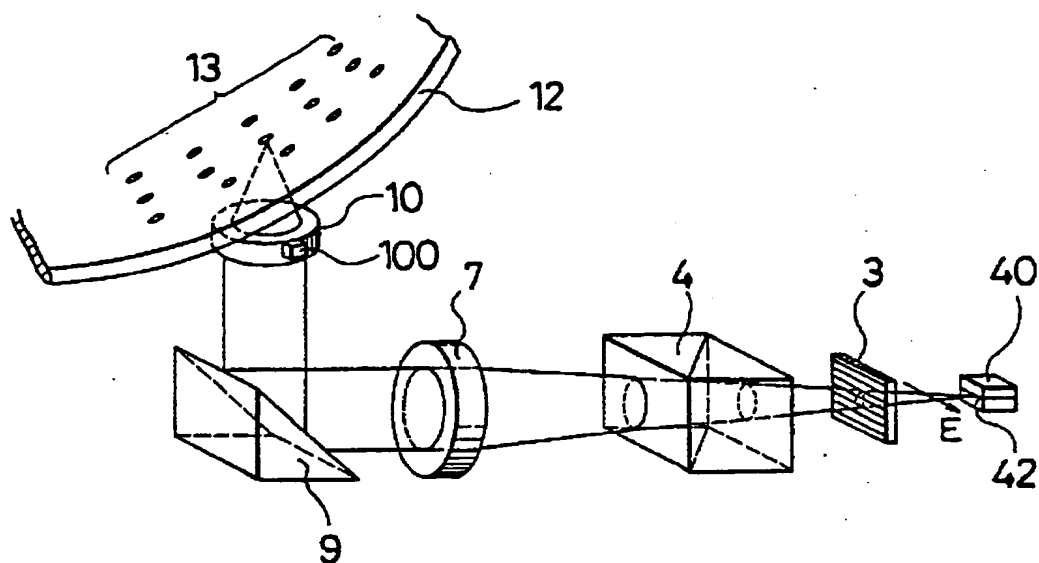


FIG. 2

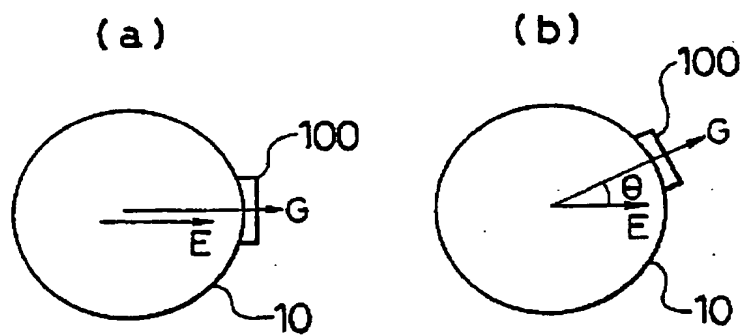
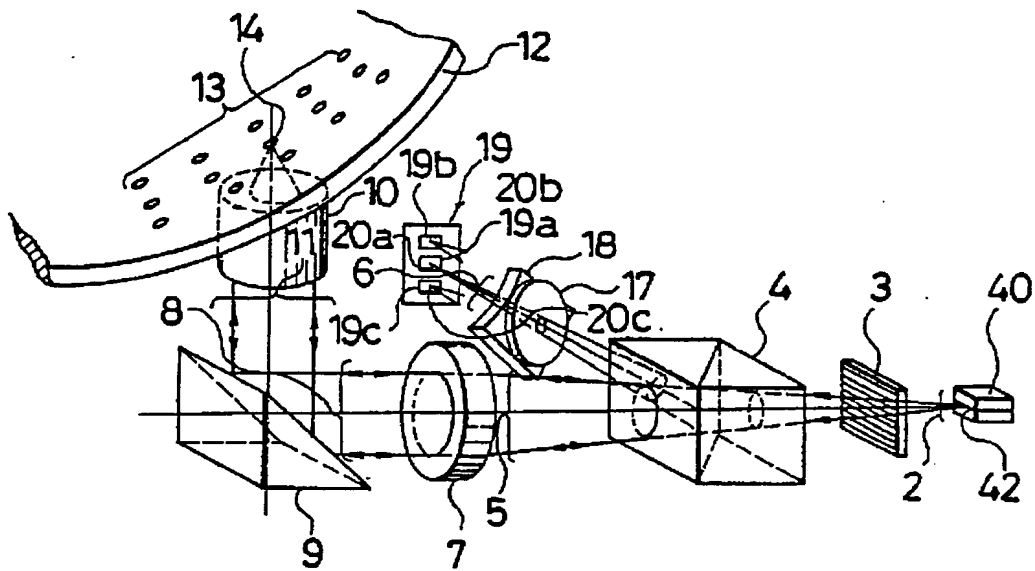
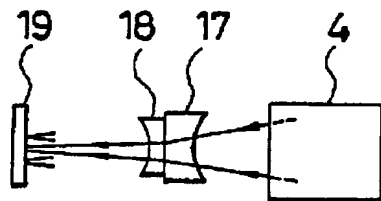


FIG. 3  
PRIOR ART

(a)



(b)



(c)

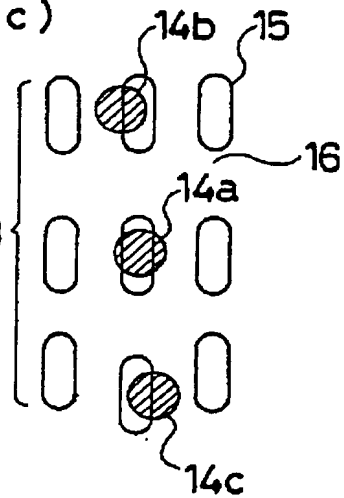
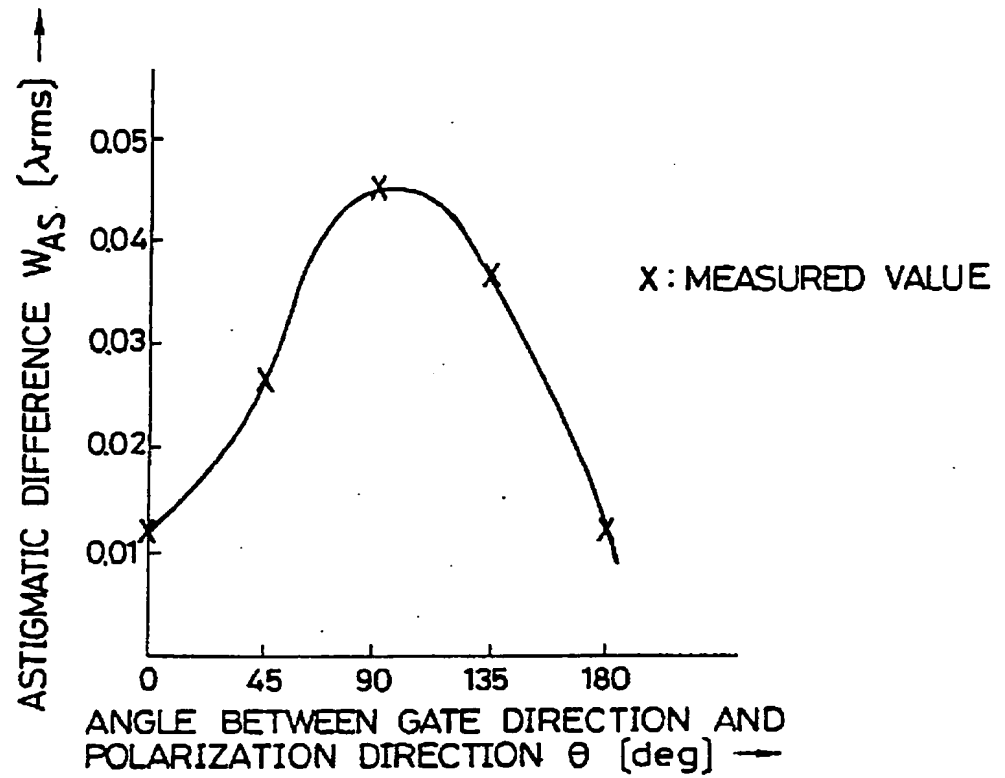


FIG. 4

(a)



(b)

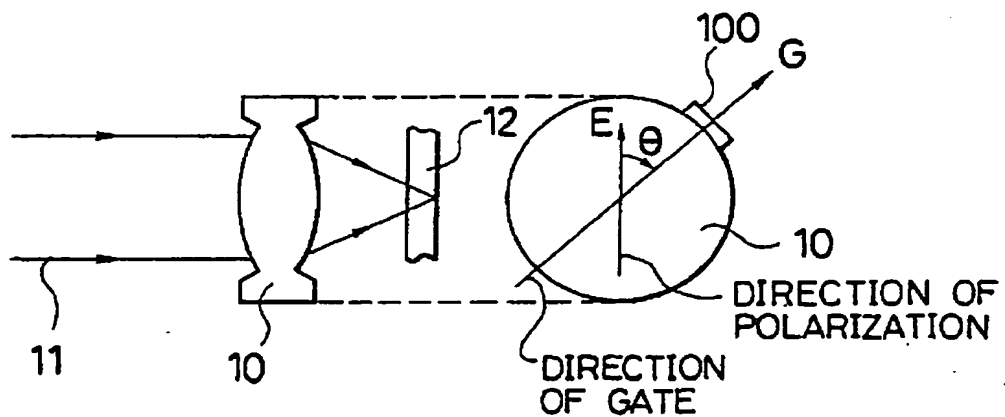


FIG. 5

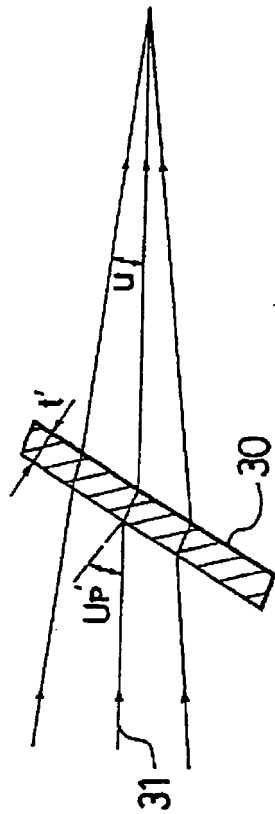


FIG. 6

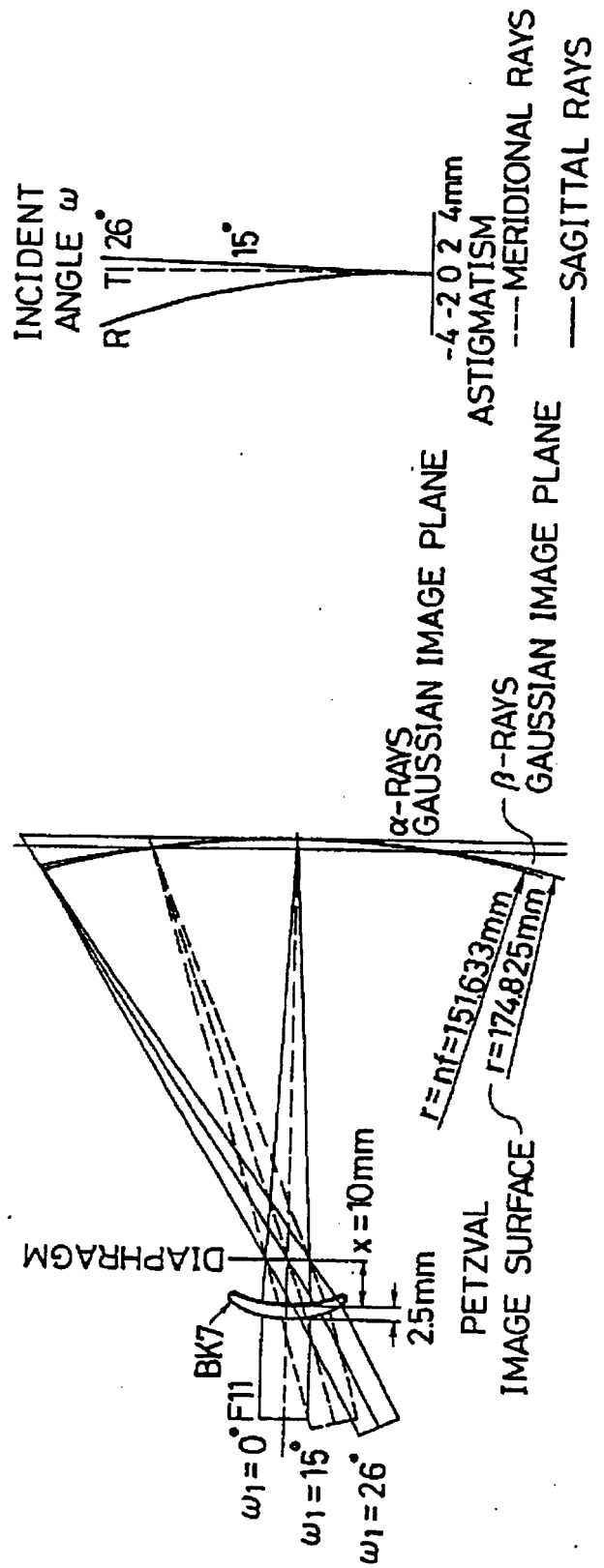
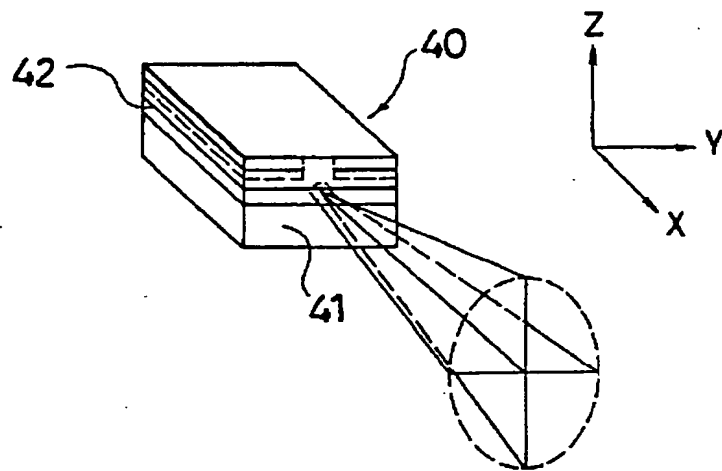


FIG. 7

(a)



(b)

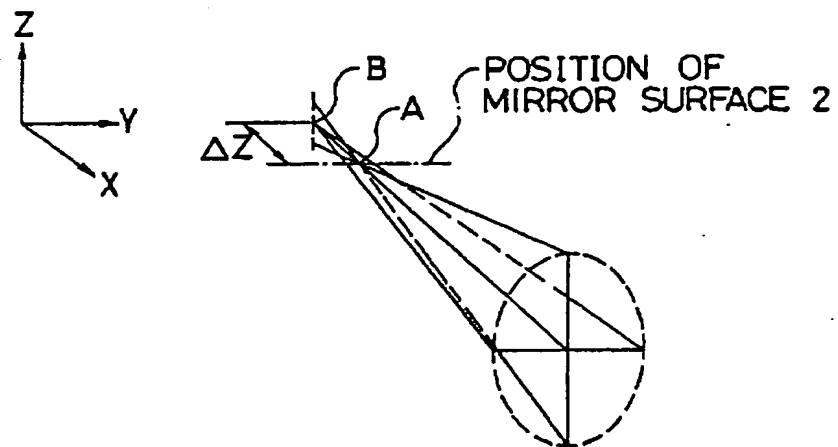
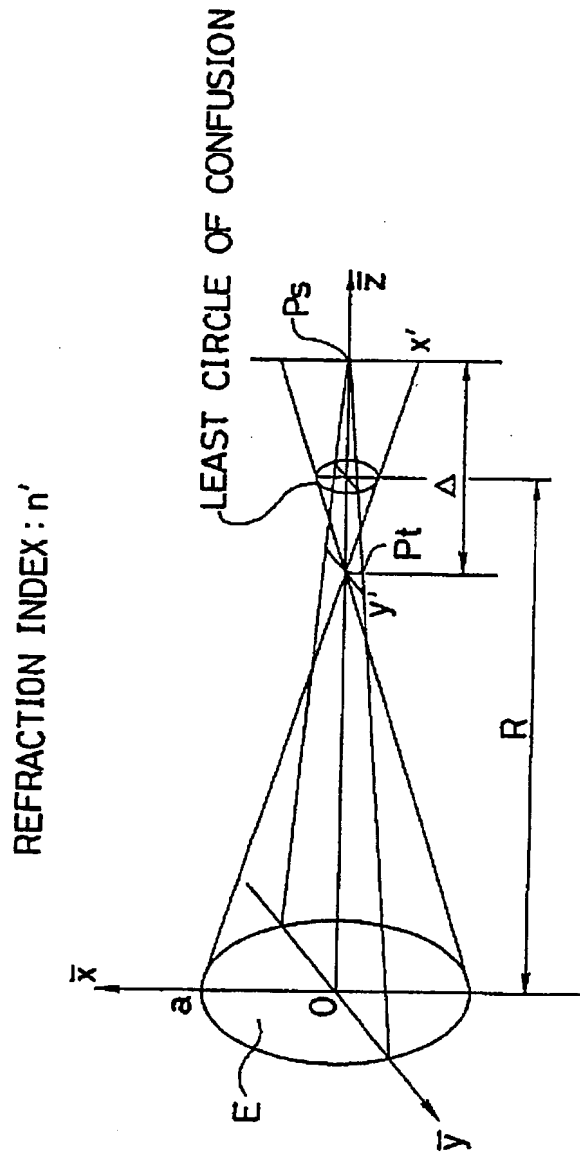


FIG. 8



$P_t$ : MERIDIONAL IMAGE POINT

$P_s$ : SAGITTAL IMAGE POINT

$a$ : APERTURE RADIUS

$\Delta$ : ASTIGMATIC DIFFERENCE

FIG. 9

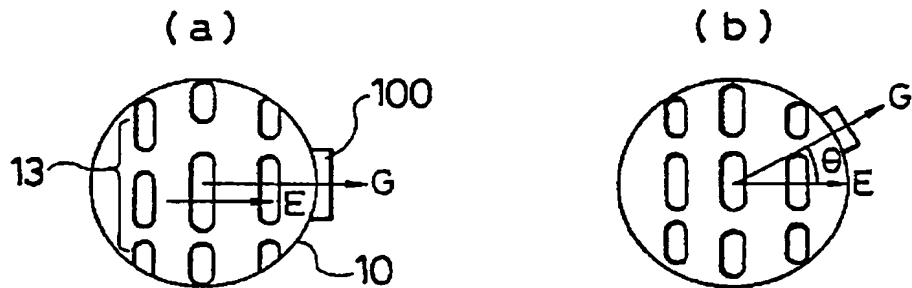
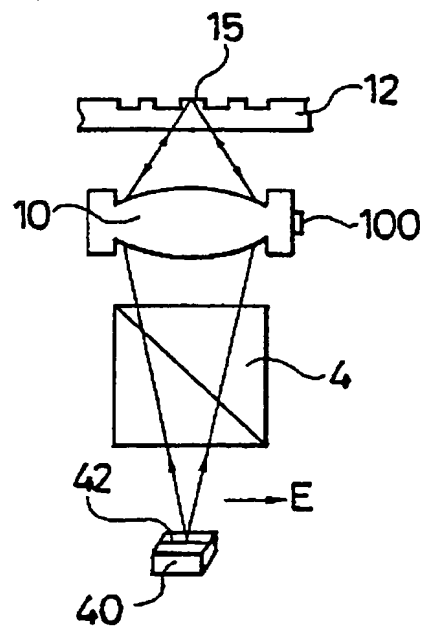


FIG. 10



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